Deciphering Earth's Movements: Unveiling Subsidence and Displacement in Capo Colonna Through SAR and CGPS

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DECIPHERING EARTH'S MOVEMENTS: UNVEILING SUBSIDENCE AND DISPLACEMENT IN CAPO COLONNA THROUGH SAR AND CGPS

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ABSTRACT

This study investigates the subsidence phenomenon in the Capo Colonna area (Calabria, southern Italy) using Synthetic Aperture Radar (SAR) data from C and X bands, and Continuous Global Positioning System (CGPS) measurements collected between 2003 and 2018. Persistent Scatterer Pair Differential Interferometry Synthetic Aperture Radar (PSP-DIFSAR) and Small Baseline Subset (SBAS) techniques were employed to produce detailed deformation maps. With ascending and descending datasets from various satellites, along with acquisition parameters such as incidence and heading angles, the Line of Sight (LOS) measurements were decomposed into vertical and east-west displacement components. This provided a comprehensive understanding of the displacement rates in the Capo Colonna peninsula, revealing significant subsidence patterns, particularly in the promontory. Varied deformation rates were observed across different sectors, with higher rates in the peninsula than in Crotone's hinterland and urban areas. The complementary comparison between SAR and CGPS data offered critical insights into the region's geodynamic behavior, enhancing risk assessment and management strategies to preserve its geological and archaeological heritage.

Index Terms— Subsidence, Lateral Displacement, Synthetic Aperture Radar (SAR), Continuous Global Positioning System (CGPS), Differential SAR Interferometry

1. INTRODUCTION

In this study, we delve into the significant geodynamic phenomena of subsidence affecting the Capo Colonna area (Southern Italy), a region with rich historical significance located in the peri-Ionian area of Crotonese, Calabria. The effects induced, in terms of settlements, by the subsidence phenomenon have been widely studied in the literature [1]. The primary problem addressed is the identification and quantification of these subtle yet critical movements of the Earth's surface, which pose risks to both the natural environment and the archaeological heritage of the area. Among the technologies that best allow for the reconstruction of kinematics and extent of the areas affected by these phenomena, there is undoubtedly SAR Interferometry. Developed in the early 1990s, it makes it possible to estimate surface displacements with sub centimeter precision, as evidenced by numerous publications on the subject [2-4]. In recent years, this technology has increasingly been joined by conventional techniques such as topographic levelling or the use of GNSS sensors [5]. In this study, mean displacement rate maps were updated in the province of Crotone, Italy, where subsidence induced by inshore and offshore subsurface fluid extraction has been carried out for more than 40 years [6-8].

2. DATA AND METHODS

The study period spans from March 2003 to October 2018, utilizing an integrated approach combining current geological knowledge with various geodetic and remote sensing techniques. The analysis primarily centers on the processing and comparison of deformation data obtained through two different satellite radar bands, C and X, alongside Continuous Global Positioning System (CGPS) measurements [9]. For the C-band analysis, data from the RADARSAT 1 and 2 satellites were utilized, covering the whole aforementioned period, and processed using the Persistent Scatterer Pair Differential Interferometry Synthetic Aperture Radar (PSP-DIFSAR) technique [10]. This method is known for its high precision in detecting and monitoring ground deformation over time, making it particularly useful for observing subtle ground movements. For the X-band, data were acquired from both the TerraSAR-X satellite, in an ascending orbit, and the COSMO-SkyMed satellite, in a descending orbit. The period for X-band data extends from 2013 to 2018, with processing conducted using the Small Baseline Subset (SBAS) technique [11]. SBAS is adept at providing time-series analysis of ground deformation, allowing for the detailed study of changes over large areas.
The selection of PSI for RADARSAT data was driven by its high spatial resolution and accuracy in monitoring deformation over time, particularly useful for detecting slow-moving deformation with stable scatterers. This choice was crucial for analyzing subsidence patterns in Capo Colonna

from 2003 to 2018. In contrast, SBAS was applied to TSX and CSK data due to its effectiveness in areas with non-linear deformation and its ability to process data from various viewing geometries. SBAS handles temporal and spatial decorrelation well, essential in dynamic environments. This dual-methodology approach enhances the study's scientific validity by leveraging the strengths of both techniques, offering a comprehensive, nuanced view of the complex deformation dynamics in the area.

Having the ascending and descending datasets, in detail the acquisition parameters such as incidence angle and heading angle, of all the analysed constellations available, it was possible to obtain the horizontal and vertical components of the displacement rates as described in [12]. These datasets were meticulously analyzed to provide a detailed characterization of the subsidence and horizontal displacement patterns in the Capo Colonna area and its hinterland till Crotone town.

3. SAR RESULTS

Average vertical deformation rates obtained from SAR data are collected and analyzed: the results are presented in the Table 1.

Table 1. Average vertical deformation rates obtained from SAR data.

Area	V_{vert} *C-band (mm/year)*	V_{vert} *X-band (mm/year)*
Capo Colonna promontory	-7.50	-7.20
Capo Colonna hinterland	-11.30	-12.0
Crotone	-3.00	-2.30

This Table provides the vertical deformation rates for different sectors of the Capo Colonna area, categorized by the SAR band used, C or X. Specifically, it outlines the average vertical deformation rates for the Capo Colonna promontory and hinterland, as well as the urban area of Crotone, illustrating the varying degrees of subsidence across these regions. For instance, the promontory of Capo Colonna exhibits average vertical deformation rates of -7.5 mm/year and -7.2 mm/year for C and X bands respectively, whereas the hinterland experiences more pronounced subsidence with rates of -11.3 mm/year and -12 mm/year, respectively. Crotone's urban area, though less affected, still shows subsidence with average rates of -3 mm/year and -2.3 mm/year for C and X bands, respectively.

In detail, the vertical component data from RADARSAT (C-band) and TerraSAR-X/COSMO-SkyMed (X-band) show significant subsidence rates in the Capo Colonna area, with the hinterland displaying lower subsidence rates than the promontory itself. The average vertical deformation rates are outlined in Figure 1a for RADARSAT and Figure 1b for TerraSAR-X/COSMO-SkyMed, demonstrating notable differences between the promontory and hinterland of Capo Colonna.

The horizontal deformation component, particularly highlighted in Figures 2a, and 2b, reveals an anomalous westward movement in the Capo Colonna promontory, contrasting with the general eastward movement along the coastal strip. This phenomenon is further elaborated through a detailed analysis of the time series data from both C and X bands, where the Capo Colonna promontory exhibits a distinctive trend of negative shifts (westward movement), in contrast to the adjacent coastal area's positive values (eastward movement).

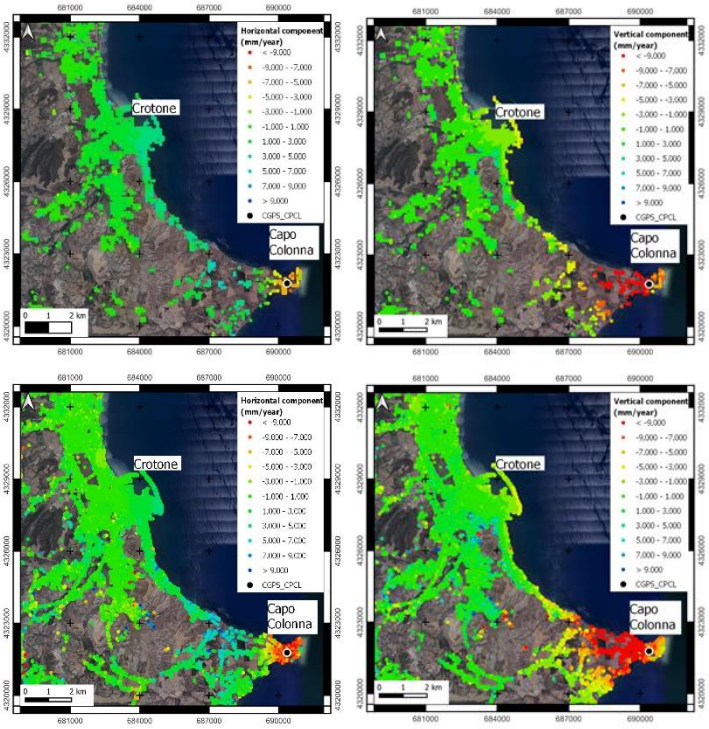

Figure 1 (Left). Vertical component in the Capo Colonna and hinterland area: (top) C-band, (bottom) X-band. Figure 1 (Right). Horizontal component in the Capo Colonna and hinterland: (top) C-band, (bottom) X-band.

4. DISCUSSION AND CONCLUSIONS

These SAR-derived results are cross-validated with CGPS measurements, which offer high-precision and continuous monitoring of ground movements. The comparison indicates a general agreement between the two methodologies in detecting ground deformations, with SAR providing a broader spatial coverage and CGPS offering point-based, continuous data. This synergistic approach enhances the reliability and comprehensiveness of the deformation analysis, leveraging the strengths of both SAR's wide-area monitoring and CGPS's high temporal resolution to create a

robust understanding of the geodynamic processes affecting the Capo Colonna area.

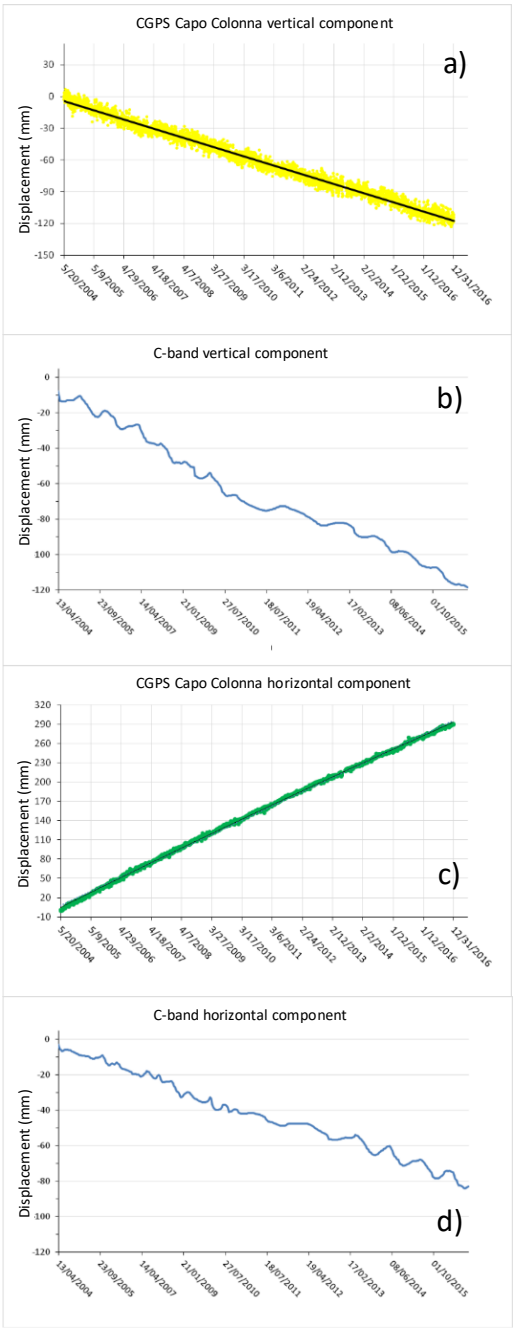

Figure 3. Comparison of the Capo Colonna CGPS (a and c) time series with those of C-band reflectors (b and d) falling within a buffer zone with a radius of 100m around the station itself.

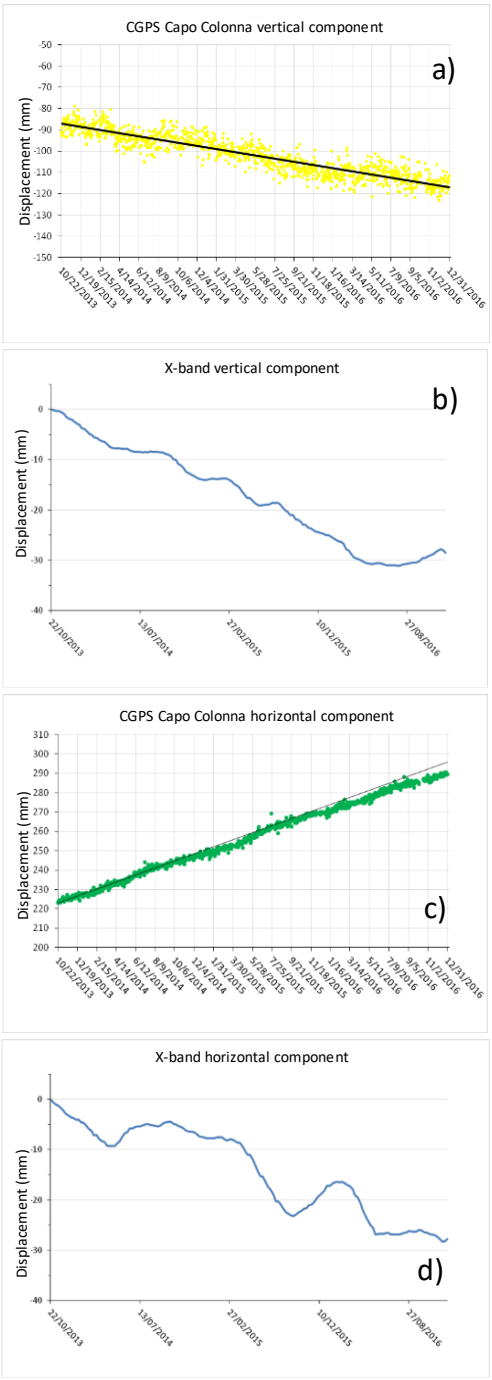

Figure 4. Comparison between time series of the vertical and horizontal components of the Capo Colonna CGPS station (a and c) with the time series of X-band SAR data (b and d) of reflectors that fall around the station.

The time series of the Capo Colonna CGPS were compared with those of RADARSAT reflectors falling within a buffer zone with a radius of 100m around the station itself. The time series of the vertical component show a progressive increase in deformation with very similar absolute values and deformation increase rates between the CGPS and SAR data. The time series for the E-O horizontal component, however, disagree. The CGPS data register a progressive shift eastward while the SAR data indicate a movement westward. From

previous observations at the scale of the entire Crotonese area, both CGPS and SAR data highlighted a general shift eastward, with only the Capo Colonna promontory characterized by a movement westward in SAR data. The discrepancy observed in the comparison of time series might be related to the recording of the general eastward movement of the entire Crotonese area by the CGPS station, and of the local westward movement (with respect to the surrounding area) of the Capo Colonna peninsula by the RADARSAT data. This is only a preliminary hypothesis, and a more in-depth study is considered appropriate to investigate this discrepancy between CGPS and SAR data in detail (Figures 3 and 4).

In summary, by integrating SAR data from two different bands with CGPS measurements, the study provides interesting insights into the geodynamic behavior at Capo Colonna. The findings, supported by Figures and data, underscore the value of combining multiple remote sensing techniques to monitor and understand ground deformation, aiding in the preservation and management of this historically and geologically significant area. This detailed analysis of Capo Colonna serves as a model for similar studies aiming to comprehend the complex dynamics of Earth's surface. Also, the findings provide valuable insights into the subsidence and displacement patterns, offering a solid foundation for future monitoring and investigation efforts in the region.

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